KVICHAK RIVER SOCKEYE SALMON STOCK STATUS AND ACTION PLAN, 2003

A REPORT TO THE ALASKA BOARD OF FISHERIES

by

Bristol Bay Staff

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EXECUTIVE SUMMARY OF KVICHAK RIVER SOCKEYE SALMON STOCK STATUS

Synopsis

In response to guidelines established in the "Sustainable Salmon Fisheries Policy" (ADF&G 2000), the Department recommended the Kvichak River sockeye salmon stock as a stock of concern in January 2001. The Board of Fisheries found that the stock met the criteria and classified Kvichak River sockeye salmon as a stock of "yield" concern" at that time. This classification is based on the definition of "yield concern" found in the policy. A "yield concern" is "a concern arising from a chronic inability, despite the use of specific management measures, to maintain expected yields, or harvestable surpluses, above a stock's escapement needs". For this determination, the most recent 5-year period (one salmon life cycle or generation) was compared to the Kvichak River data set from 1956 to 1996 (Table 1). This Board cycle, with 3 more years of return data, and failing to meet the minimum biological escapement goal in each of those years, the Department is recommending the Kvichak River sockeye to be elevated to a stock of "management concern". Management concern is defined in the policy as "a concern arising from a chronic inability, despite the use of specific management measures, to maintain escapements for salmon stocks within the bounds of the BEG". A management concern is more severe than a yield concern. Using the most recent 5-year data set, yields and escapements from 1999 and 2000 were compared to pre-peak and peak years only, and yields and escapements from 2001, 2002 and 2003 to off-cycle years only.

The high degree of variability over the 40-year span of the data set reflects the long-term cycles coinciding with changes in the Pacific Decadal Oscillation (Hare et al. 1999). It is plausible that the PDO is in the process of shifting to a less productive period for Bristol Bay salmon. The literature states that major PDO regimes have persisted for 20 to 30 years, the most recent shift occurring in 1976-77 and resulting in a period of high productivity for Bristol Bay salmon. A shift to a less favorable regime might suggest that Kvichak River returns of the last 8 years are expected and that higher yields might not be sustainable. If a PDO shift is occurring, this comparison of recent yields is better illustrated by using the entire Kvichak River data set (1956-98) than by using a recent 20-year data set (1978-98).

Harvest

Table 2 and Figure 2 summarize the yield analysis for the Kvichak River. The actual yield was less than the median yield in all years (both peak and off-cycle) of the most recent 5-year period in which yield was zero in 2002 and only slightly above one percent in 2003. The term "lower range of historical harvest" is not defined in the "Sustainable Salmon Fisheries Policy." Thus the degree of yield concern and the point at which a yield concern is classified are subject to interpretation. Figure 2 is provided to illustrate graphically the yield data for the recent 5 years in the context of historical values.

Escapement

Table 3 summarizes the escapement analysis for the Kvichak River. During the most recent 5 years, the escapement goal was made only once, the pre-peak year of 1999. During the past 10-years the goal has been met only in 1994, 1995, 1998 and 1999. The off-cycle escapement goal was changed from 4,000,000 to 2,000,000 (variable) in 1997 (implemented in 1998, Table 4). Escapements in 1996 and 1997 would not have met the current off-cycle goal of 2,000,000 although the shortfall is not alarming. ADF&G is concerned with the 70% shortfall in escapement during a Kvichak peak year (2000). There have been two pre-peak (1959 and 1964) and no peak year escapements, which were less than the 2000 escapement. The Department feels that with the decrease in marine productivity indicated by recent smolt/return ratios and a possible PDO shift, the current trends in Kvichak River returns could continue.

Outlook

The 2004 sockeye salmon run for the Kvichak River is anticipated to be an average pre-peak year based on parent year and sibling returns. Typically, for a pre-peak year the majority of Kvichak River sockeye salmon are 5 year-old 2-ocean fish. The parent year for this 2-ocean component was from the 1999 brood year, which was an average return; the escapement goal of 6.0-million sockeye was met.

Alaska Board of Fisheries Action

During the meetings in January 2001, the Board looked at numerous proposals and four action plans (Bristol Bay staff, 2001) that could potentially lower the exploitation rate on Kvichak sockeye salmon in Bristol Bay. Of those action plans considered, the following is a brief summary of the Board's actions. Earlier triggers for the Naknek/Kvichak District: both gear groups (set and drift) move into the Naknek River Special Harvest Area (NRSHA) when the Kvichak escapement falls more than 1-day behind the cumulative escapement goal curve on or after June 27. When moving into the NRSHA, fishing in the Egegik District is moved to the Egegik River Special Harvest Area (ERSHA) until the fishery moves back out into the Naknek/Kvichak District. In the Ugashik District, if the Kvichak stocks cannot withstand an exploitation rate greater than 40%, fishing time between June 16 and June 23 is reduced to no more than 48-hours. If the NRSHA is in effect prior to June 29, then Ugashik District will move into the Ugashik River Special Harvest Area (URSHA) up to June 29 (Figure 3).

In response to the guidelines established in the Sustainable Salmon Fisheries Policy, the Alaska Board of Fisheries, during the 10/01-03/03 workshop, classified the Kvichak River sockeye salmon stock as a management concern.

Table 1. Historical yield, escapement and total inshore return of Kvichak River sockeye salmon.

	Actual Yield		Actual Escapement		Total Inshore Return	
Year	Pre-Peak & Peak	Off-cycle	Pre-Peak & Peak	Off-Cycle	Pre-Peak & Peak	Off-Cycle
1956		4,168,343		9,443,318		13,611,661
1957		3,540,189		2,842,810		6,382,999
1958		549,396		534,785		1,084,181
1959	281,930		680,000		961,930	
1960	7,976,500		14,630,000		22,606,500	
1961		6,863,814		3,705,849		10,569,663
1962		1,833,401		2,580,884		4,414,285
1963		223,459		338,760		562,219
1964	763,486		957,120		1,720,606	
1965	17,785,664		24,325,926		42,111,590	
1966		4,168,575		3,775,184		7,943,759
1967		1,800,652		3,216,208		5,016,860
1968		387,565		2,557,440		2,945,005
1969	3,760,565		8,394,204		12,154,769	
1970	16,581,224		13,935,306		30,516,530	
1971		3,764,861		2,387,392		6,152,253
1972		342,150		1,009,962		1,352,112
1973		21,791		226,554		248,345
1974	148,595		4,433,844		4,582,439	
1975	1,605,407		13,140,450		14,745,857	
1976		1,458,180		1,965,282		3,423,462
1977		739,464		1,341,144		2,080,608
1978		3,815,636		4,149,288		7,964,924
1979	13,418,829		11,218,434		24,637,263	
1980	12,743,074		22,505,268		35,248,342	
1981		5,234,733		1,754,358		6,989,091
1982		1,858,475		1,134,840		2,993,315
1983		16,534,901		3,569,982		20,104,883
1984	12,523,803		10,490,670		23,014,473	
1985	6,183,103		7,211,046		13,394,149	
1986		787,303		1,179,322		1,966,625
1987		3,526,824		6,065,880		9,592,704
1988		2,654,364		4,065,216		6,719,580
1989	11,456,509		8,317,500		19,774,009	
1990	10,551,217		6,970,020		17,521,237	
1991		3,808,873		4,222,788		8,031,661
1992		5,718,947		4,725,864		10,444,811
1993		5,287,523		4,025,166		9,312,689
1994	13,893,613		8,337,840		22,231,453	
1995	17,391,906		10,138,720		27,530,626	
1996		1,983,269		1,450,578		3,433,847
1997		179,480		1,503,732		1,683,212
1998		1,069,294		2,296,074		3,365,368
MED	11,003,863	1,983,269	9,266,462	2,557,440	21,002,731	5,016,860
MAX	17,785,664	16,534,901	24,325,926	6,065,880	42,111,590	20,104,883
MIN	148,595	21,791	680,000	226,554	961,930	248,345
1999	6,392,296		6,196,914		12,589,210	
2000	1,026,986		1,827,780		2,854,766	
2001		330,538		1,095,348		1,425,886
2002		0		703,884		703,884
2003 [a]		35,742		1,686,804		1,722,546

a Preliminary

Table 2. Comparison of recent pre-peak, peak and off-cycle yields to historical median yield for Kvichak River sockeye salmon.

Year	Actual Yield	Median Yield: Pre-Peak & Peak 1959-95, n = 16	Median Yield: Off-cycle 1956-98, n = 27	Difference	% deviation from Med. [a]	Yield < Lower Range [b]	Frequency of Occurrence[c]
1999	6,392,296	11,003,863		-4,611,567	-42	No	6 (n=16)
2000	1,200,000	11,003,863		-9,803,863	-89	No	3 (n=16)
2001	330,538		1,983,269	-1,652,731	-83	No	3 (n=27)
2002	0		1,983,269	-1,983,269	-100	No	0 (n=27)
2003	35,742 [d]		1,983,269	-1,947,527	-98	No	1 (n=27)

[a] Percent deviation = (Actual - Median) / Median

[b] Lower range of Pre-Peak and Peak years was 148,595 and Off-cycle years was 21,791.

[c] The number of yield observations (1956-1998) which are less than the yield of the current year

[d] 2003 yield is a preliminary estimate.

Table 3. Escapement analysis for Kvichak River sockeye salmon, 1999-2003.

Year	Actual Escapement	Escapement Goal	Difference	% deviation from Goal [a]	Escapement > Goal	Frequency of Occurrence[b]
1999	6,196,914	6,000,000	196,914	3	Yes	3 (n=16)
2000	1,827,780	6,000,000	-4,172,220	-70	No	2 (n=16)
2001	1,095,348	2,000,000	-904,652	-45	No	4 (n=27)
2002	703,884	2,000,000	-1,296,116	-65	No	3 (n=27)
2003	1,686,804	2,000,000	-313,196	-16	No	9 (n=27)

[a] Percent deviation = (Actual - Goal) / Goal

[b] The number of escapement observations (1956-1998) which are less than the escapement of the current year.

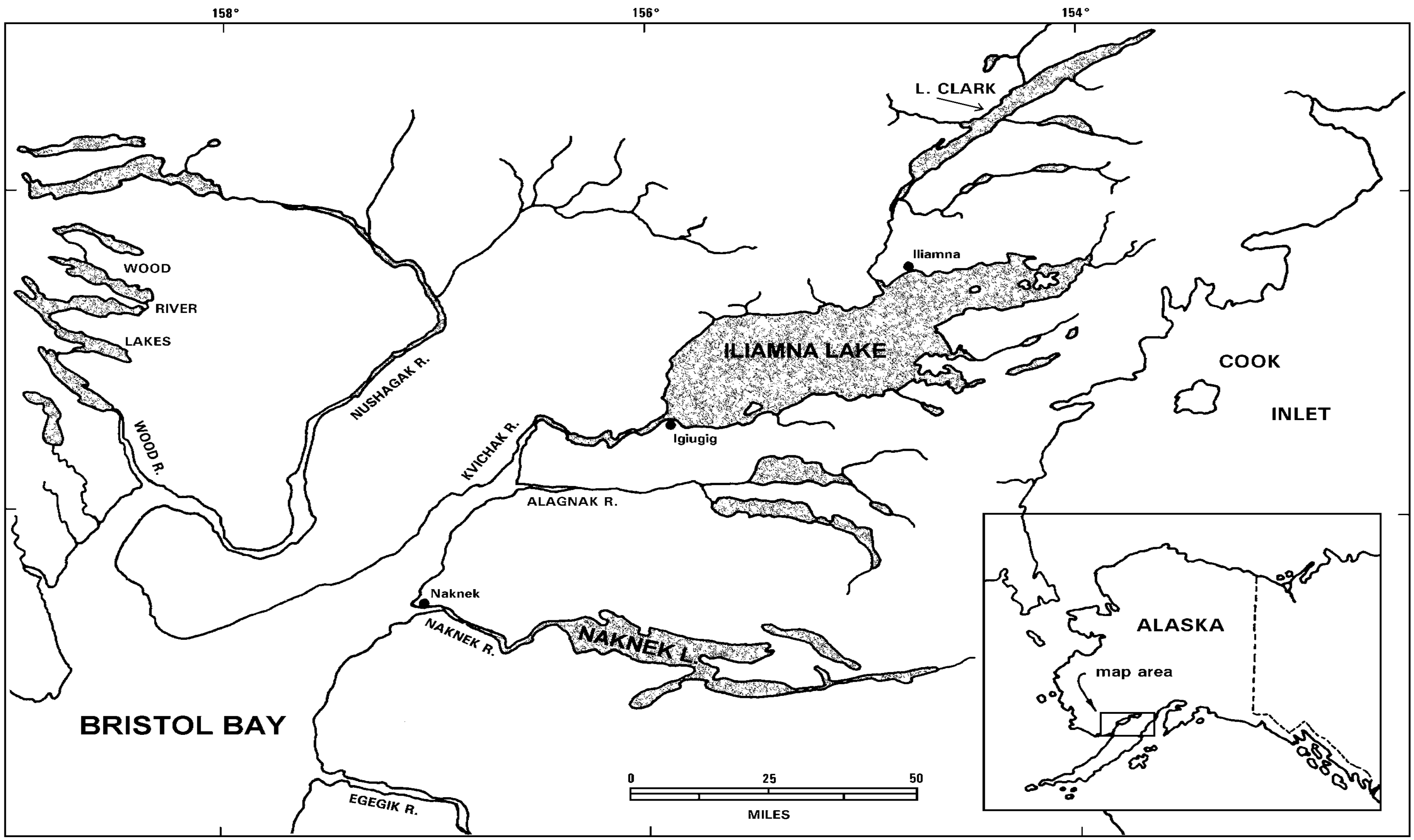
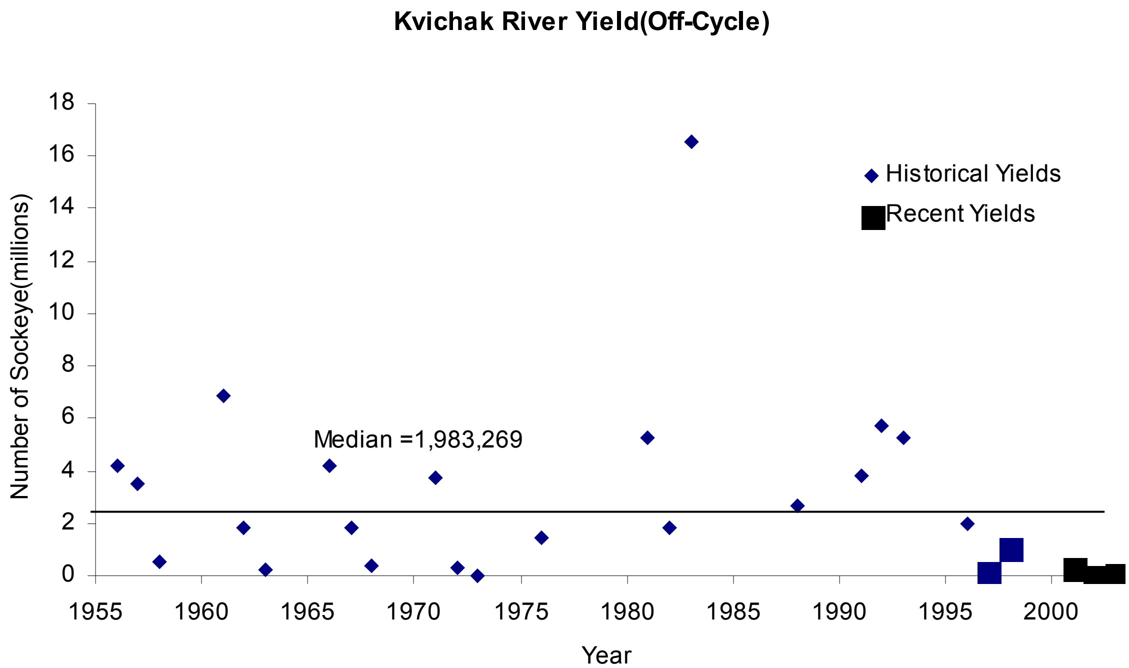


Figure 1. Map of Kvichak River drainage.



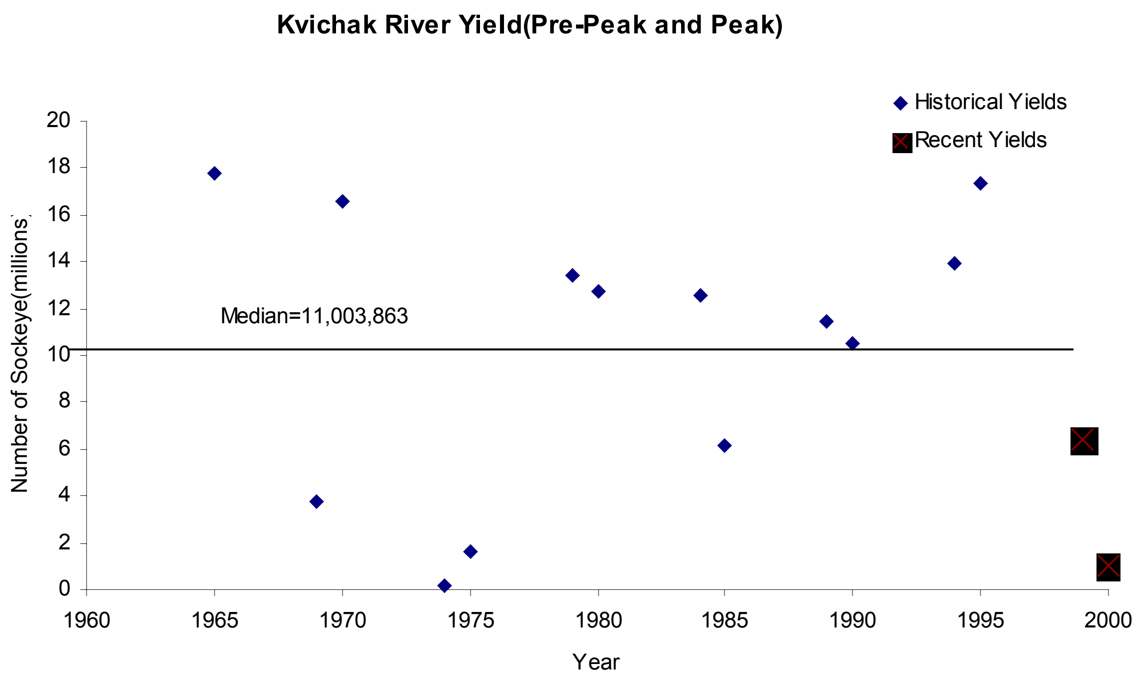


Figure 2. Kvichak River sockeye salmon yield by year.

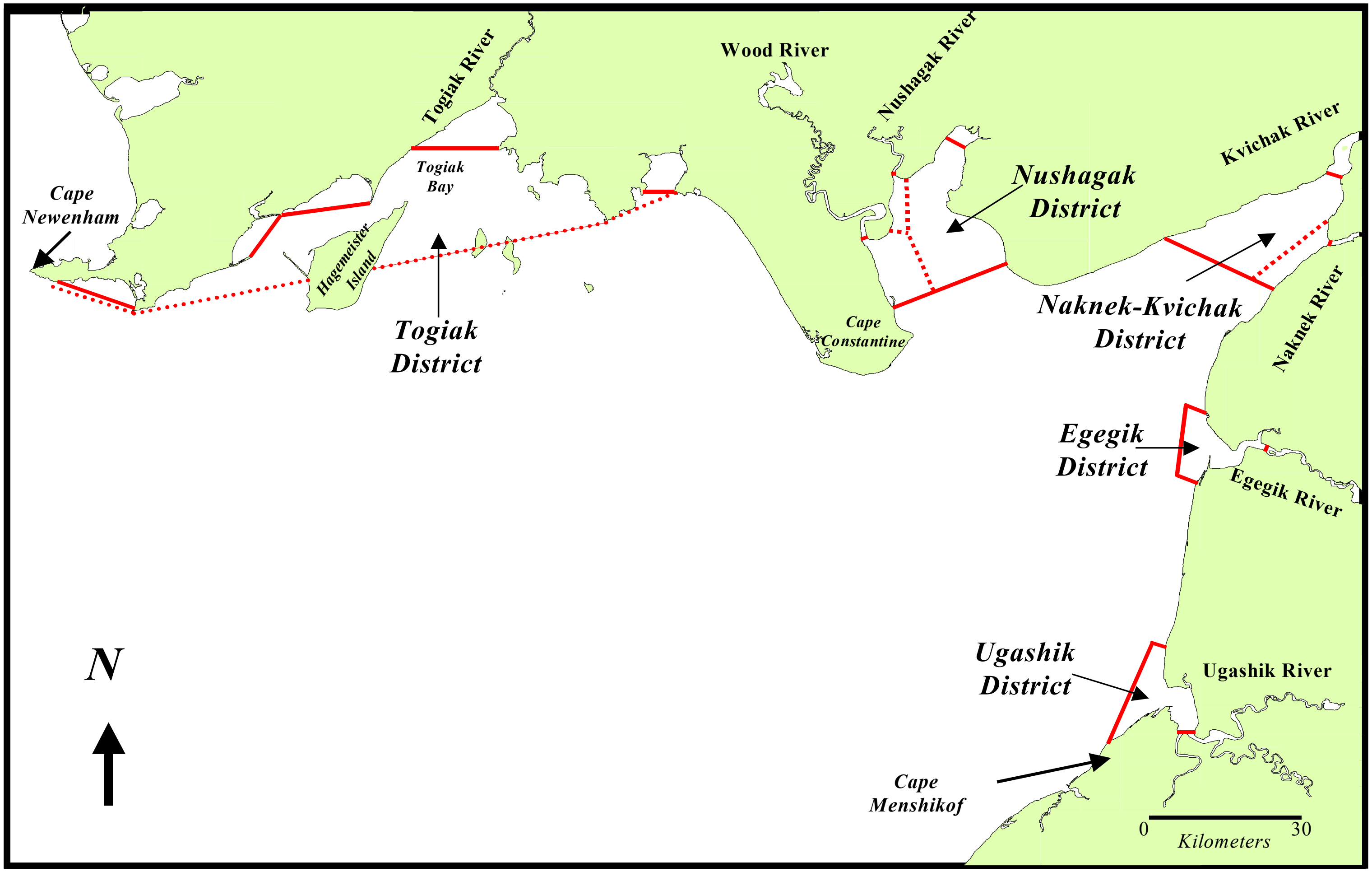


Figure 3. Map of Bristol Bay showing major rivers and fishing districts.

MANAGEMENT ACTION PLAN OPTION FOR ADDRESSING STOCK OF CONCERN AS OUTLINED IN THE SUSTAINABLE FISHERIES POLICY

Kvichak River Sockeye Salmon Management Plan Review/Development

Current Stock Status

In response to the guidelines established in the Sustainable Salmon Fisheries Policy, the Board of Fisheries during the October 1-3, 2003 work session classified the Kvichak River sockeye salmon stock as a management concern. This determination was based on the inability, despite the use of specific management measures, to maintain escapement for a salmon stock within the bounds of the BEG for four of the past five years.

C&T use finding and the amount necessary

The Board of Fisheries has made a positive finding for Customary and Traditional Use for all salmon in the Bristol Bay area of 157,000 to 172,171 salmon. Of those 55,000 to 65,000 sockeye salmon were determined reasonably necessary for Kvichak River drainage.

Habitat Factors Adversely Affecting the Stock

There are no habitat factors adversely affecting the Kvichak stock within the entire drainage.

Do New Or Expanding Fisheries On This Stock Exist?

Presently, there are no new or expanding fisheries on this stock. There are no proposals specific to expanding fisheries on this stock.

Existing Management Plans

Board reviews existing management plan for consistency with principles and criteria of Sustainable Salmon Fisheries Policy or adopts new management for the stock consistent with the principles and criteria of the Sustainable Salmon Fisheries Policy. The following are the current regulations:

5 AAC 06.200. FISHING DISTRICTS, SUBDISTRICTS, AND SECTIONS.
5 AAC 06.310. FISHING SEASONS.
5 AAC 06.320. FISHING PERIODS.
5AAC 06.355. BRISTOL BAY COMMERCIAL SET AND DRIFT GILLNET SOCKEYE SALMON FISHERIES MANAGEMENT AND ALLOCATION PLAN.
5 AAC 06.359. EGEGIK RIVER SOCKEYE SALMON SPECIAL HARVEST AREA MANAGEMENT PLAN.

5 AAC 06.360. NAKNEK RIVER SOCKEYE SALMON SPECIAL HARVEST AREA MANAGEMENT PLAN.
5 AAC 06.364. NAKNEK/KVCHIAK DISTRICT COMMERCIAL SET AND DRIFT GILLNET SOCKEYE SALMON FISHERIES MANAGEMENT AND ALLOCATION PLAN.
5 AAC 06.365. EGEGIK DISTRICT COMMERCIAL SET AND DRIFT GILLNET SOCKEYE SALMON FISHERIES MANAGEMENT AND ALLOCATION PLAN.
5 AAC 09.200 DESCRIPTION OF DISTRICTS AND SECTIONS.
5 AAC 09.310 FISHING SEASONS.

Action Plan Development

Kvichak Sockeye Salmon Action Plan Goal

To rebuild the Kvichak sockeye salmon run back to historical levels by attaining the BEG.

Previous actions: During the BOF meeting in January of 2001, the Department presented a summary of four potential action plans (Bristol Bay staff, 2001). The Board in its deliberation, reduced the exploitation rate on Kvichak stocks in the three eastside districts. In the Ugashik District, when the preseason forecast of Kvichak sockeye salmon does not provide for an exploitation rate greater than 40%, fishing time from June 16 to June 23 can not exceed 48-hours. In addition, if the NRSHA is in effect anytime before June 29, fishing will be restricted to the URSHA. In the Egegik District, when the NRSHA is open to commercial fishing then fishing in the Egegik District is restricted to the ERSHA and will remain in the ERSHA until fishing resumes in the Naknek/Kvichak District. In the Naknek/Kvichak District, the district is closed to both gear groups when Kvichak River escapement falls one or more days behind the cumulative escapement goal curve on or after June 27. When fishing the NRSHA, an OEG is in effect raising the upper end of escapement goal range from 1.4 million to 2.0-million sockeye salmon.

Management under the current regulations: In 2001, the forecast for the Kvichak River projected a harvestable surplus of only 900,000 sockeye with an escapement goal of 2.0-million. To minimize potential harvest within the Naknek/Kvichak District, fishing time prior to June 23 was reduced from the 96-hours per week to 48-hours per week. In addition, the Kvichak Section was closed to drift gillnet gear, but was left open to set gillnet gear. On June 27, the Kvichak River escapement was more than one day behind the cumulative escapement goal curve, the district closed and the fishery moved into the NRSHA. Fishing proceeded in the NRSHA fishing every tide, first with the drift and then set gillnet gear. When the drift gillnet fleet fished, periods for the most part began at the 15-foot flood and closed on the 15-foot ebb. The set gillnet fleet fished from 10-foot flood to the 10-foot ebb. When escapement in the Naknek River increased and the likelihood of exceeding the upper end of the goal was imminent, additional fishing time was announced. To increase harvest potential, the drift fleet fished back-to-back tides on two occasions. The fishery remained in the NRSHA until July 23. The final escapement for the Naknek was 1.8-million and the Alagnak River tower operated with Federal Subsistence funding counted 615,000 sockeye and the Kvichak total was almost 1.1-million sockeye. Escapement surveys conducted from the air yielded an estimate of slightly more than 6,300 chinook salmon in the Naknek River drainage; the goal is 5,000. In the Alagnak drainage no official goal exists but the average index is 4,200 and the estimated count was 5,400 chinook salmon.

In 2002, the forecast projected no surplus harvest for the Kvichak, so the department closed the Naknek/Kvichak District June 1. This early closure put Egegik in the ERSHA, Ugashik in the URSHA on June 1. Fishing began on June 28 in the NRSHA and continued every tide using the same strategy as in 2001. The fleet remained in the NRSHA until July 29 when only the Naknek Section was opened. No deliveries were reported when the Naknek Section opened. The sockeye escapement for the Naknek River was nearly 1.3 million, 770,000 to the Alagnak River and 705,000 for the Kvichak River. Escapement for chinook salmon conducted from the air estimated slightly more than 7,500 in the Naknek River drainage and 3,760 in the Alagnak River.

In 2003, the forecast projected a run of 2.6 million sockeye salmon, which was 600,000 above the minimum escapement goal. The department took a cautious approach to the season based on past forecast uncertainty. The Kvichak Section was closed June 1 and announced that it was not expected to open again. The Naknek Section would open only if a large volume of fish was detected in the Naknek Section, and escapement into the Naknek River was under way. The Naknek Section opened on June 22 and June 25, two short periods fishing the flood portion of the tide only. On June 26, with the Kvichak more than a day behind the escapement goal curve, the Naknek Section closed and the NRSHA opened. Periods again were structured as before drift gillnet fleet began fishing at the 15-foot flood stage and the period ended at the 15-foot ebb. The set gillnet fleet fished the 10-foot flood to 10-foot ebb. This again changed through out the fishery depending on the escapement rate. The Naknek Section opened on July 21; the Kvichak Section remained closed for the entire season. The sockeye escapement for the Naknek River was slightly more than 1.8 million, the Alagnak River was 3.7 million sockeye and the Kvichak was only 1.7 million. A complete aerial survey of the Naknek drainage for chinook salmon was not completed in 2003; however, of the three systems surveyed all exceeded the historical average; a count of 6,100 chinook includes all but Big Creek. The estimate was 8,200 chinook salmon for the Alagnak River in 2003.

Action Plan Alternatives

ACTION 1. Lower the exploitation rates on Kvichak stocks within the Naknek/Kvichak District.

Objective: Modify existing management plans to further reduce the exploitation rate of Kvichak stocks within the Naknek/Kvichak District when necessary.

Background: Current changes to the east side management plans have resulted in some savings to the Kvichak, however, the escapement goals were still not met in 2001, 2002 or 2003. However, escapement goals were met or exceeded in the two other systems within the Naknek/Kvichak District. As stated previously both the Alagnak and Naknek River escapement goals were met in 2001, 2002 and 2003.

Specific action recommended to implement the objective

Earlier trigger by starting the commercial salmon fishing season in the special harvest area for all east side districts when the Kvichak River forecast is less than some set number that is greater than 2.0-milion for an off-cycle year and 6.0-million for a pre-peak or peak year. This trigger would affect the Naknek/Kvichak, Egegik and Ugashik Districts as early as June 1.

Cost/Benefits Analysis

During years of low returns Kvichak stock may potentially receive some benefits from the earlier trigger for inriver fisheries. The amount of benefit is unknown and will not necessarily guarantee achieving the BEG. There are potential costs that go along with an inriver fishery.

1) Lower product quality of the harvest.

2) Larger pulses of fish entering into the escapement when commercial fishing is not occurring in the traditional section areas outside the rivers.

3) High numbers of boats confined to small areas leading to disorderly fisheries.

4) Less precision balancing allocation issues between gear groups in-river.

5) Short notice fisheries for most of the season to control escapement.

6) Less precision managing for escapement within the BEG range.

7) Potential impacts to the escapement of other species such as chinook and chum salmon.

Subsistence issues/considerations
There would be no loss of subsistence opportunity in this plan.

Performance measures
The Kvichak BEG met annually, no inriver fisheries and a level of harvest occurs on the Kvichak stock that produces average yields.

Research plan to address stock of concern
A research plan is not applicable to this proposed action.

LITERATURE CITED

Alaska Department of Fish and Game and the Alaska Board of Fisheries. 2000. Sustainable salmon fisheries policy for the State of Alaska. Alaska Department of Fish and Game, Juneau. 14 pp.

Bristol Bay Staff. 2000. Kvichak River sockeye salmon stock status and action plan 2000. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A00-37, Anchorage.

Hare, S. R., N. J. Mantua, and R. C. Francis. 1999. Inverse production regimes: Alaska and west coast Pacific salmon. Fisheries 24: 6-14.

Menard, J. and J. D. Miller. 1997. Report to the Alaska Board of Fisheries on the stock composition of sockeye salmon catches within the eastside fishing districts, 1983-1995. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A97-31, Anchorage.

Rogers, D. E., and P. H. Poe. 1984. Escapement goals for the Kvichak River system. Unpublished Report FRI-UW-8407, Fisheries Research Institute, University of Washington, Seattle.

Sands, T., S. Morstad, and K. Weiland. 2003. Salmon spawning ground surveys in the Bristol Bay area, Alaska, 2002. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A03-07, Anchorage.

APPENDIX A

Juvenile Sockeye Salmon Assessment and Limnological Studies of Lake Illiamna: Summary of Findings

Prepared by: J. A. Edmundson/J. M. Edmundson

Among the many ecologically diverse drainages in the Bristol Bay region, the Kvichak River system supports the most variable sockeye salmon run in terms of abundance. Annual (1956-2002) sockeye returns have varied from a high of approximately 38 million to a low of 300 thousand fish (Figure 1). For most of the last 50 years, adult returns to the Kvichak River have exhibited a fairly distinct five-year cycle, with three years of low returns and two years of high returns. However, in the last few years, the 5-year cycles in abundance have either strongly diminished or ended. In addition, several consecutive seasons of poor returns forced fishery closures in the Naknek-Kvichak district to protect sockeye bound for the Kvichak River and Lake Illiamna. Yet, despite these conservative management actions, poor sockeye returns for brood years 2000-2002 failed to meet the 2 million fish minimum escapement goal. In the last couple of years, the Kvichak River sockeye run has improved, but current production falls well below historical (1980-1995) levels.

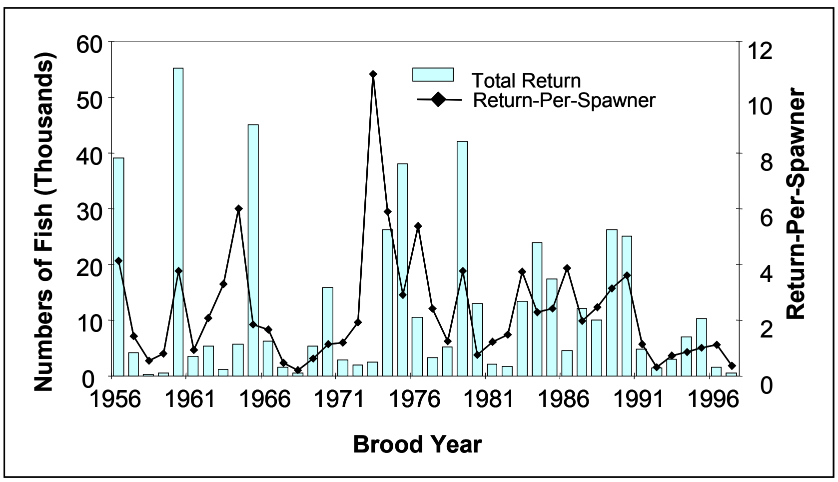


Fig. 1. Sockeye total returns and return-per-spawner by brood year for the Kvichak River system, 1956-1997.

The U. S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS) funded a three-year (1999-2002) project in response to the recent (1997-1998) poor returns of sockeye salmon in western Alaska. This Western Alaska Disaster Grant (WADG) project was a joint venture with Alaska Department of Fish and Game, Central Region Limnology (ADF&G-CRL), University of Alaska Fairbanks (UAF), University of Washington, Fisheries Research Institute (UW-FRI), and NOAA, Northwest Fisheries Science Center to examine freshwater aspects of sockeye salmon production in the Kvichak River system. Our work focused on integrating limnological and fisheries data from Lake Illiamna to test or evaluate the current hypotheses about the cyclic patterns in production and elucidate factors underlying the apparent recent decline in stock productivity.

In Illiamna Lake, as in other sockeye nursery lakes, zooplankters are the main source of food for juvenile sockeye after they migrate from near shore areas to the pelagic zone. Our preliminary analysis of the historical limnological data (1963-1975) indicate that cyclopoid copepod abundance was negatively related to the total number of smolt produced annually (Figure 2A) and the size of age-1 smolts was positively related to both *Daphnia* (Figure 2B) and calanoid copepod abundance (Figure 2C) suggesting the system may have alternated between top-down (consumer) and bottom-up (resource) control. We characterize the pre-peak years as being resource limited or under bottom-up control (Figure 2B-C) whereas peak and post-peak years are more driven by consumers; i.e., under top-down control (Figure 2A). In other words, at peak escapements the system nears carrying capacity and planktivorus sockeye fry graze down larger-sized *Daphnia* and calanoids. Consequently, juvenile sockeye then switch to feeding more heavily on less nutritious *Cyclops*, which results in reduced fry growth and higher mortality. Such a system may provide a plausible mechanism for the observed cycles in sockeye returns. However, results from our retrospective analysis do not explain the recent decline in sockeye production for the Kvichak River system.

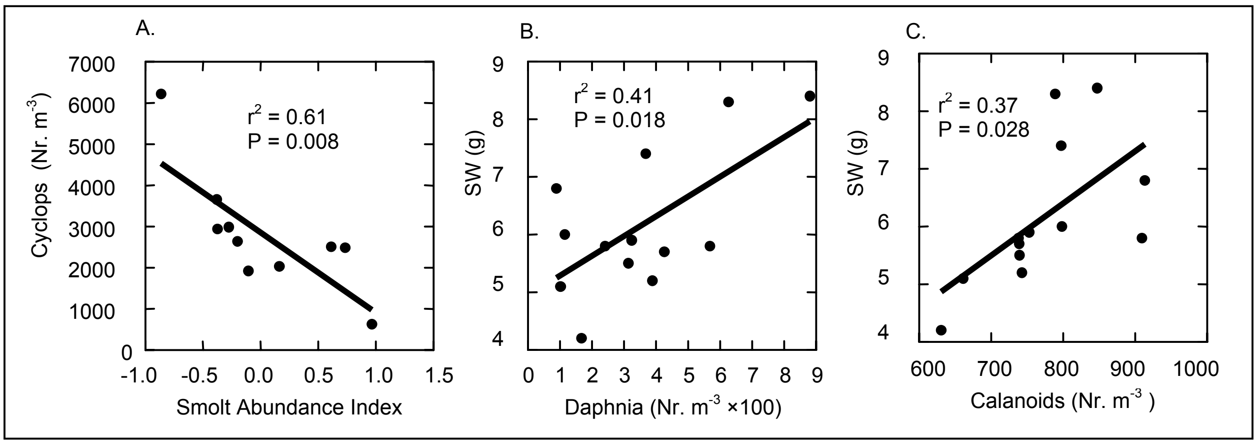


Fig. 2. Relationship between (A) *Cyclops* density and sockeye smolt abundance; and (B) age-1 sockeye smolt weight (SW) as a function of *Daphnia* and (C) calanoid density, Lake Illiamna.

Considering the recent data, total average zooplankton density in Lake Illiamna was higher, about twice as much, in 2000 (6,807/m^3) compared to 2001 (3,454/m^3). Although the 2001 zooplankton density estimate was the lowest estimate on record, current densities of zooplankton well overlap the range of historical (1963-1975) levels 4,493/m^3-9,208/m^3). In addition, the species composition of the zooplankton community in 2000 and 2001 resembles that of the historical data. Overall, the bulk (50-70%) of the total macrozooplantkon density (and biomass) is composed of cyclopoid copepods. Unfortunately, our limnological study spans too few years to permit direct comparisons between recent variability in freshwater conditions (e.g., zooplankton) and indices of fry or smolt production.

On the other hand, based on our collective work on other sockeye systems, we found that mean population size of smolt was a good integrator of freshwater conditions imposed on juvenile sockeye salmon and the inverse relationship between average smolt size and fish density can be used to infer carrying capacity and equivalent spawners. For instance, threshold escapement relative to size of age-1 smolt (i.e., where smolt size does not fluctuate with the number of spawners) is around 7 million for this system (Figure 3), which represents the mid-point of the current escapement goal range (2-10 million for off-cycle years, 6-10 million for pre-peak and peak years). In addition, above this threshold level the data correspond to only the pre-peak and peak years of the 5-year cycle, whereas the data below represent the off-cycle years. While this pattern was expected, it is also consistent with our idea about oscillating top-down and bottom-up control of the pelagic foodweb. The pre-peak and peak years represent the upper carrying capacity when competition for food resources (*Cyclops*) is high, thus freshwater growth is reduced and size of smolts is generally smaller than in the off-cycle years when grazing pressure is relaxed, larger zooplankton (*Daphnia* and *Diaptomus*) are more abundant, and the size of smolts larger.

Additionally, based on a robust multi-lake model (21 lakes; 83 lake years) relating mean age-1 smolt size to total smolt density we developed for Alaskan lakes that clearly shows density dependent growth, the threshold smolt size (5.5 g) occurs at about 100,000 total smolt per square kilometer of lake area. Given the combined surface areas of Lake Illiamna and Lake Clark (2,889 km^2), this threshold density equates to a total 289 million smolt, which is 40% more than the recent (i.e., 1987-1996 brood years) average production estimate (201 million) for the Kvichak River derived via hydroacoustics. We interpreted this predicted level of smolt production as another indicator of the overall system carrying capacity, though it is difficult to extrapolate this to the number of equivalent spawners beyond conducting a simple ratio exercise using standard freshwater survival estimates.

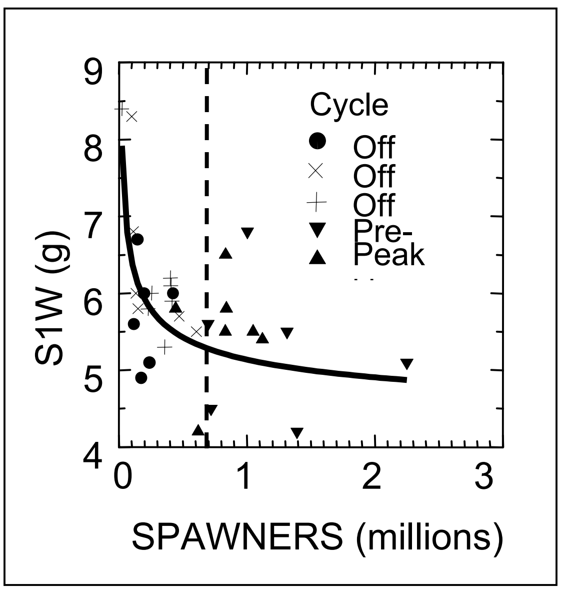


Fig. 3. Curvilinear relationship between mean age-1 smolt size (S1W) and sockeye escapement for Lake Illiamna, brood years 1968-1999. Data are fitted to a power model, the dash lines represents system carrying capacity.

Bioenergetically based food web models provide an effective method for quantifying trophic interactions by simulating the transfer of energy from one trophic level up to the next. Our collaborators Drs. Ole Mathisen and Norma Jean Sands recently developed a stationary

ECOPATH (food web) model for Lake Illiamna. ECOPATH commonly solves for standing stocks (biomass). The results to date of this mass-balancing model suggest that juvenile sockeye production is strongly tied to nutrients derived from salmon carcasses (Figure 4). This model demonstrates that a greater influx of salmon carcasses leads to increased primary and secondary productivity in subsequent rearing years, which is invested in juvenile sockeye biomass rather than other fish species or benthos. The greatest response in the biomass of rearing sockeye juveniles occurs in the second and particularly the third year following the peak escapement. These results seem consistent with food web theory in that under high planktivorous fish densities, as happens in the year immediately following peak escapement, increases in fish density reduces the efficiency with which nutrients and energy are passed along to rearing sockeye juveniles because of reduced size and biomass of large herbivorous zooplankton. In contrast, increases in nutrients tend to have a greater impact when planktonic food webs are dominated by large-sized grazers (e.g., *Daphnia*), as we proposed happens in off-cycle years. However, in the ECOPATH model there is still much uncertainty surrounding the trophic levels of other fish species and the model does not incorporate abiotic effects that might affect community dynamics such as climatic changes or non-food competitive interactions.

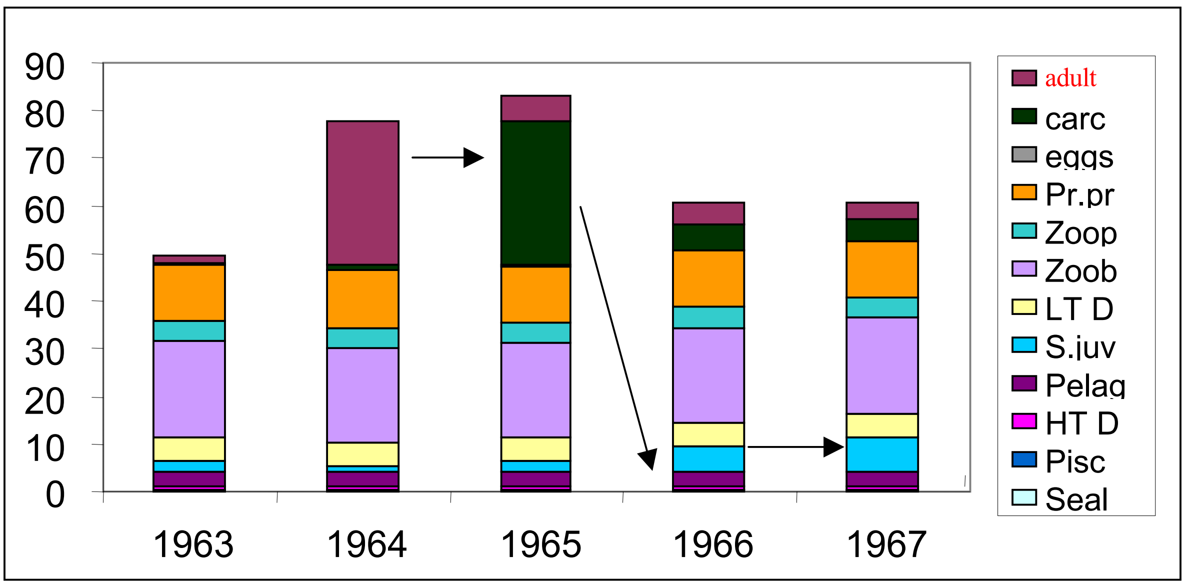


Fig. 4. Results from ECOPATH model for years 1963-1967 showing the biomass distribution for the Illiamna Lake ecosystem. The major annual differences are seen in the returning adult spawners (top section of each bar) and the carcasses (the second from the top section given in black). The large number of adults arriving in model year 1964 (September 1964-August 1965) becomes the carcasses of model year 1965. The largest biomass of juvenile sockeye is in model year 1967 (which is spring/summer of 1968); these are the results of spawning in 1965-1967.

Sedimentary stable nitrogen isotope ($\delta^{15}N$) signatures in lake sediments can index past abundances of sockeye spawners in some systems and provide insight concerning historical levels of pelagic productivity. Preliminary analysis of the sedimentary $\delta^{15}N$ data for Illiamna Lake (Figure 5) indicates that the sedimentation rate is slow (~0.05 cm/yr) making it difficult to calibrate with escapement. Therefore, we cannot detect the 5-year cycles in downcore $\delta^{15}N$

values (parts per mil, ‰) that would otherwise shed some light on human-induced depensatory mortality as a cause for the observed cycles in sockeye production. Nonetheless, the data from Core 5 show an obvious decline in $\delta^{15}N$ beginning in the early 20th century, commensurate with the development of the commercial fishery. The $\delta^{15}N$ signature drops from about 8-9‰ to 4-5‰ suggesting historical escapement several hundred years prior to commercial exploitation was higher, but quite variable. However, while some would argue otherwise, there is no clear indication that the decline in $\delta^{15}N$ signatures in lake sediments implies a decrease in pelagic productivity or reduced carrying capacity of sockeye nursery lakes. That is, data are currently insufficient to develop the relationship between sedimentary $\delta^{15}N$ and robust indices of productivity such as water nutrient concentrations, plankton abundance, size and abundance of sockeye juveniles, and adult return-per-spawner. Nonetheless, in terms of internal nutrient cycling it is possible that long-term (decadal) reductions in marine-derived nutrients, as indicated by the sedimentary $\delta^{15}N$ record, have yet to be expressed in the Lake Illiamna ecosystem.

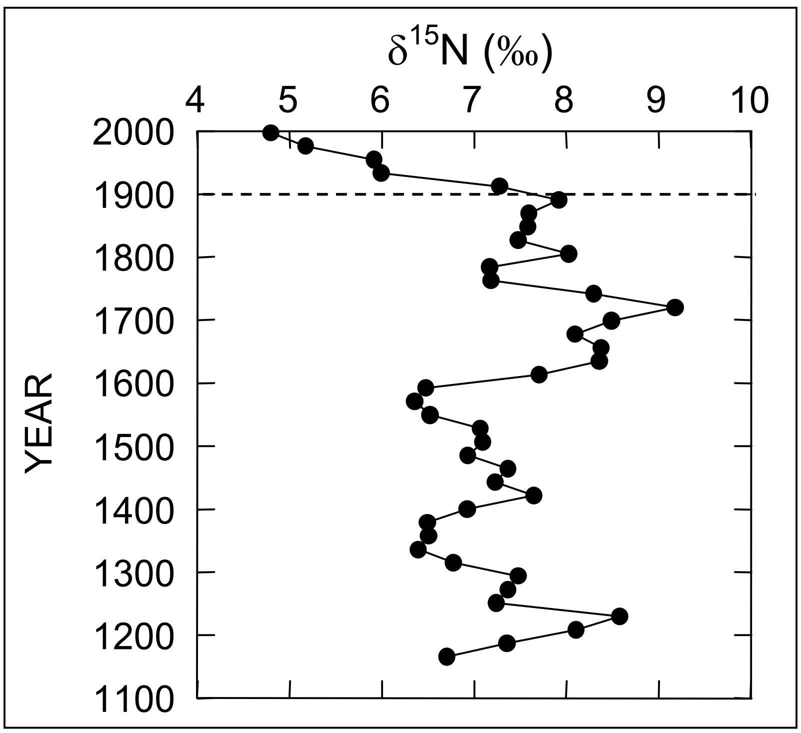


Fig. 5. Temporal trend in sedimentary $\delta^{15}N$ for the last 850 years in Lake Illiamna. Dashed line represents the onset of the commercial fishery in Bristol Bay.

As to the recent decline in sockeye production of the Kvichak River sockeye, it has been suggested that warmer climatic conditions have led to earlier ice breakup and accelerated growth of juvenile sockeye (Dr. Daniel Schindler, UW-FRI, personal communication). The result is that in recent years a larger proportion of smolts migrated to sea after spending one winter in the lake rather than two. Because age-1 smolts are smaller than age-2 smolts they experience higher mortality at sea. This shift toward younger and smaller smolts is hypothesized as a cause for the recent decline in sockeye production for the Kvichak system.

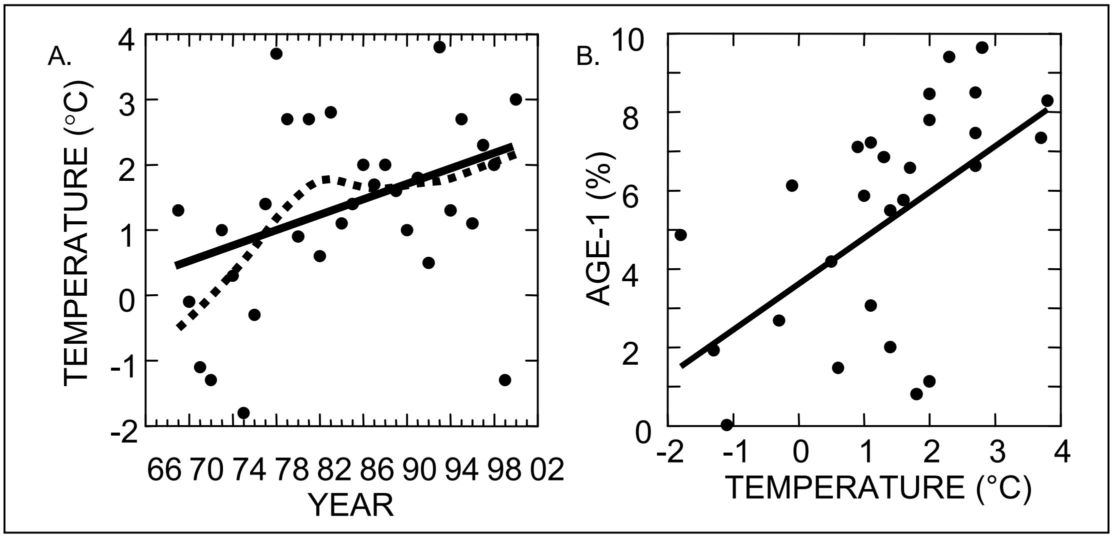


Fig. 6. Time series of (A) mean annual air temperature, King Salmon (dashed is the LOWESS fit and solid line is the linear fit); and (B) the relationship between the proportion of age-1 sockeye smolts and air temperature.

Our preliminary analysis of the temperature and smolt data show that there has been a warming trend over the past 30 years for the Bristol Bay region (Figure 6A) and there is a significant positive relationship between the proportion of age-1 smolt produced from the Kvichak River system and local air temperature (Figure 6B). Over the past decade or so, there has also been a substantial increase in the proportion of age-1 smolt (Figure 7). However, with respect to regional climate changes, a shift in age composition has not been clearly demonstrated in other nearby sockeye nursery lakes. In addition, assessing freshwater growth patterns of sockeye salmon under changing thermal regimes is complicated by the interactions between temperature, food resources and fish density. While we do not discount the strong influence of temperature on the growth of juvenile sockeye salmon, it is not clear to us whether the decline in Kvichak sockeye production is directly related to a lengthening of the growing season and altered age composition of rearing sockeye juveniles.

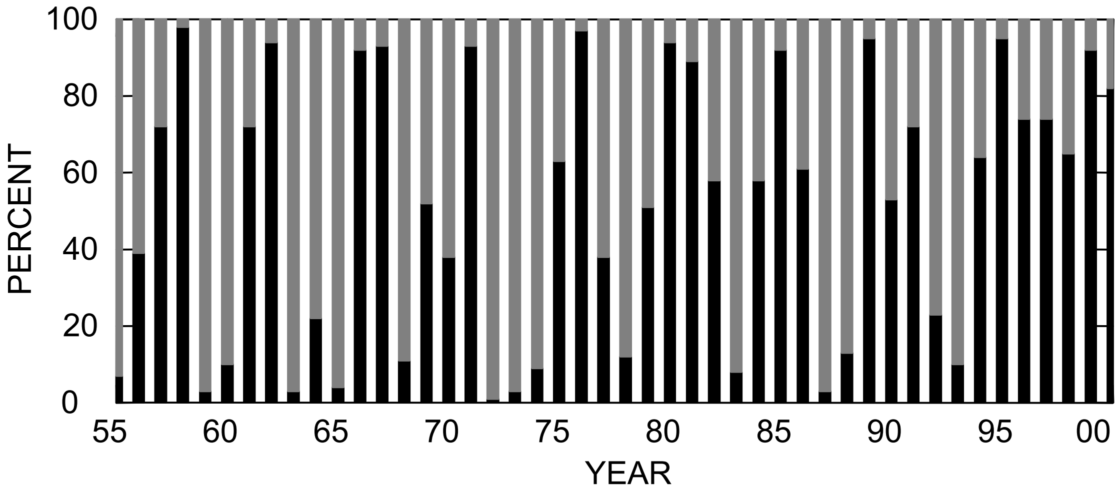


Fig. 7. Age composition of Kvichak River sockeye smolt by year of migration (age-1 black bars; age-2 gray bars) 1955-2001

In summary, available biological information is inconclusive about the cause or maintenance of the cyclic pattern in adult returns for the Kvichak system. However, we hypothesize that productivity of juvenile sockeye is in part regulated by temporal shifts in the abundance, size structure and composition of the macrozooplankton community mediated by nutrient subsidies and variable fry density. While we have good understanding of responses of aquatic food webs to nutrients and predation, we still know very little of how these fundamental processes affect the production of juvenile sockeye salmon in freshwater and adult returns. In addition, it is difficult to determine whether the cause for the decline in production of the Kvichak River sockeye salmon is related to freshwater processes because our recent time series of limnological data is too short. We plead for the collection of consistent and long-term data sets on stock and recruitment along with information on the ecology of sockeye salmon. Without these complementary data sets, information on smolt abundance, size and age composition may be the best measure of system (freshwater) performance. Contrary to the recent assertion that smolt and limnological data are useless in evaluating escapement goals, information on lake dynamics and juvenile sockeye have been used successfully to help evaluate, revise and set escapement goals for a variety of systems in Bristol Bay, Upper and Lower Cook Inlet, Prince William Sound and Kodiak areas. One of the important contributions of this study to the debate about freshwater versus marine influences on the productivity of sockeye salmon is that our preliminary results show significant links between nutrient –foodweb dynamics in freshwater and their relationships with the size structure and productivity of juvenile sockeye salmon.